

CHAPTER 4

STATE OF THE SCIENCE

This final chapter contains selected abstracts and a bibliography of FY 2003 publications from scientific journals treating the global observation of ocean heat, carbon, fresh water, and sea level change. A select number of abstracts of particularly relevant scientific papers are presented first, chosen by the principal investigators (PI) of the science projects funded by NOAA's Office of Climate Observation. Website urls follow the bibliographic reference if the publication and expanded abstract can be found online.

4.1 Selected Abstracts

Bourassa, M. A., 2004: An Improved Seastate Dependency For Surface Stress Derived from In Situ and Remotely Sensed Winds. *Advances in Space Res.*, **33** (7), 1136-1142.
http://www.coaps.fsu.edu/~bourassa/pubs/Bourassa2004_stress_model.pdf

ABSTRACT

An improved model is developed for the dependency of surface turbulent stress on wave characteristics. Recent studies have used differences between satellite and in situ observations to gain insights into the physical processes that might be related to air-sea interaction. Both scatterometers and buoys provide very accurate measurements of wind speed. Differences between these measurements can be explained in terms of the different mechanisms to which the instruments respond. A physically-based flux model is developed herein. Prior results suggest that the stress parameterizations, converting neutral equivalent wind speed to stress, applied to in situ observations differ subtly from those that should be used for scatterometer-derived winds. These differences are due to water waves modifying the surface stress. This model provides a physical explanation of the observed differences, and provides a model for calculating stresses from scatterometer winds. The model is validated with recent in situ observations gathered under severe conditions. The model explains more wave-related variability in surface stress than previous models.

Cai, W., M. J. McPhaden, and M. A. Collier, 2004: Multidecadal fluctuations in the relationship between equatorial Pacific heat content anomalies and ENSO amplitude. *Geophys. Res. Lett.*, **31**, L01201, doi:10.1029/2003GL018714.
<http://www.agu.org/pubs/crossref/2004/2003GL018714.shtml>

ABSTRACT

Observations over the past 20 years indicate that equatorial Pacific Ocean heat content variations associated with El Niño-Southern Oscillation (ENSO) cycles lead sea surface temperature (SST) anomalies in the equatorial cold tongue by about 7 months. However, an asymmetry exists in the relationship between SST and heat content: positive SST anomalies related to El Niño are stronger than negative SST anomalies related to La Niña for the same magnitude (but opposite sign) heat content anomaly. In this study, we analyze a multi-century simulation using the CSIRO Mark 3 coupled climate model to show that a similar asymmetry exists in some decades but not in others. This non-stationarity appears to be a consequence of modulations by a mode of multidecadal variability which affects the temperature of upwelled water and the efficiency with which upwelling generates SST anomalies.

Centurioni, L. R., P. P. Niiler, and D.-K. Lee, 2004: Observations of inflow of the Philippine Sea surface water into the South China Sea through the Luzon Strait. *J. Phys. Oceanogr.*, **34**, 113-121.

[http://ams.allenpress.com/amsonline/?request=get-abstract&doi=10.1175%2F1520-0485\(2004\)034%3C0113:OOIOPS%3E2.0.CO%3B2](http://ams.allenpress.com/amsonline/?request=get-abstract&doi=10.1175%2F1520-0485(2004)034%3C0113:OOIOPS%3E2.0.CO%3B2)

ABSTRACT

Velocity observations near the surface made with Argos satellite-tracked drifters between 1989 and 2002 provide evidence of seasonal currents entering the South China Sea from the Philippine Sea through the Luzon Strait. The drifters cross the strait and reach the interior of the South China Sea only between October and January, with ensemble mean speeds of 0.7 ± 0.4 m s⁻¹ and daily mean westward speeds that can exceed 1.65 m s⁻¹. The majority of the drifters that continued to reside in the South China Sea made the entry within a westward current system located at 20°N that crossed the prevailing northward Kuroshio path. In other seasons, the drifters looped across the strait within the Kuroshio and exited along the south coast of Taiwan. During one intrusion event, satellite altimeters indicated that, directly west of the strait, anticyclonic and cyclonic eddies resided, respectively, north and south of the entering drifter track. The surface currents measured by the crossing drifters were much larger than the Ekman currents that would be produced by an 8–10 m s⁻¹ northeast monsoon, suggesting that a deeper westward current system, as seen in historical watermass analyses, was present.

Coale, K. H., K. S. Johnson, F. P. Chavez, K. O. Buesseler, R. T. Barber, M. A. Brzezinski, W. P. Cochlan, F. J. Millero, P. G. Falkowski, J. E. Bauer, R. H. Wanninkhof, R. M. Kudela, M. A. Altabet, B. E. Hales, T. Takahashi, M. R. Landry, R. R. Bidigare, Z. Chase, P. G. Strutton, G. E. Friederich, M. Y. Gorbunov, V. P. Lance, A. K. Hiltling, M. R. Hiscock, M. Demerest, W. T. Hiscock, K. A. Sullivan, S. J. Tanner, R. M. Gordon, C. L. Hunter, V. A. Elrod, S. E. Fitzwater, S. Tozzi, M. Koblizek, A. E. Roberts, J. Herndon, D. Timothy, S. L. Brown, K. E. Selph, C. C. Sheridan, B. S. Twining, and Z.I. Johnson, 2004: Southern ocean iron enrichment experiment: carbon cycling in high-and low-Si waters. *Science*, **304** (5669), 408-414.
<http://www.nicholas.duke.edu/news/dickbarber416.pdf>

ABSTRACT

The availability of iron is known to exert a controlling influence on biological productivity in surface waters over large areas of the ocean and may have been an important factor in the variation of the concentration of atmospheric carbon dioxide over glacial cycles. The effect of iron in the Southern Ocean is particularly important because of its large area and abundant nitrate, yet iron-enhanced growth of phytoplankton may be differentially expressed between waters with high silicic acid in the south and low silicic acid in the north, where diatom growth may be limited by both silicic acid and iron. Two mesoscale experiments, designed to investigate the effects of iron enrichment in regions with high and low concentrations of silicic acid, were performed in the Southern Ocean. These experiments demonstrate iron's pivotal role in controlling carbon uptake and regulating atmospheric partial pressure of carbon dioxide.

Feely, R.A., C. L. Sabine, K. Lee, W. Berelson, J. Kleypas, V. J. Fabry, and F.J. Millero, 2004: Impact of anthropogenic CO₂ on the CaCO₃ system in the oceans. *Science*, **305** (5682), 362–366.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=15256664&dopt=Abstract&holding=f1000

ABSTRACT

Rising atmospheric carbon dioxide (CO₂) concentrations over the past two centuries have led to greater CO₂ uptake by the oceans. This acidification process has changed the saturation state of the oceans with respect to calcium carbonate (CaCO₃) particles. Here we estimate the in situ CaCO₃ dissolution rates for the global oceans from total alkalinity and chlorofluorocarbon data, and we also discuss the future impacts of anthropogenic CO₂ on CaCO₃ shell-forming species. CaCO₃ dissolution rates, ranging from 0.003 to 1.2 micromoles per kilogram per year, are observed beginning near the aragonite saturation horizon. The total water column CaCO₃ dissolution rate for the global oceans is approximately 0.5 +/- 0.2 petagrams of CaCO₃-C per year, which is approximately 45 to 65% of the export production of CaCO₃.

Firing, Y. L., M. A. Merrifield, T. A. Schroeder, and B. Qiu, 2004: Interdecadal Sea Level Fluctuations at Hawaii, *J. Phys. Oceanogr.*, **34**, 2514–2524.
<http://www.soest.hawaii.edu/oceanography/bo/FMSQ04.pdf>

ABSTRACT

Over the past century, tide gauges in Hawaii have recorded interdecadal sea level variations that are coherent along the island chain. The generation of this signal and its relationship to other interdecadal variability are investigated, with a focus on the last decade. Hawaii sea level is correlated with sea surface height (SSH) over a significant portion of the North Pacific Ocean, and with the Pacific–North America (PNA) index, which represents teleconnections between tropical and midlatitude atmospheric variations. Similar variations extend well below the thermocline in World Ocean Atlas temperature. Comparison with NCEP reanalysis wind and pressure shows that high (low) sea level phases around Hawaii are associated with an increase (decrease) in the strength of the Aleutian low. The associated wind stress curl pattern is dynamically consistent with observed sea level anomalies, suggesting that sea level at Hawaii represents large-scale changes that are directly windforced in concert with the PNA. Atmospheric modulation, as opposed to Rossby wave propagation, may explain the linkage of Hawaii sea level to North American sea level and ENSO events. A wind-forced, baroclinic Rossby wave model replicates some aspects of the interdecadal SSH variations and their spatial structure but fails to predict them in detail near Hawaii. The accuracy of wind products in this region and over this time period may be a limiting factor. Variations in mixed layer temperature due to surface heat flux anomalies may also contribute to the interdecadal sea level signal at Hawaii.

Hare, J. E., C. W. Fairall, W. R. McGillis, B. Ward, and R. Wanninkhof, 2004: Evaluation of the NOAA/COARE air-sea gas transfer parameterization using GasEx data. *J. Geophys. Res.*, **109** (C8).
<http://cires.colorado.edu/science/projects/rp-hareJ01.html>

INTRODUCTION

During the two recent GasEx field experiments, direct covariance measurements of air-sea carbon dioxide fluxes were obtained over the open ocean. Concurrently, the National Oceanic and Atmospheric Administration/Coupled-Ocean Atmospheric Response Experiment air-sea gas transfer parameterization was developed to predict gas transfer velocities from measurements of the bulk state of the sea surface and atmosphere. The model output is combined with measurements of the mean air and sea surface carbon dioxide fugacities to provide estimates of the air-sea CO₂ flux, and the model is then tuned to the GasEx-1998 data set. Because of differences in the local environment and possibly because of

weaknesses in the model, some discrepancies are observed between the predicted fluxes from the GasEx-1998 and GasEx-2001 cases. To provide an estimate of the contribution to the air-sea flux of gas due to wave-breaking processes, the whitecap and bubble parameterizations are removed from the model output. These results show that moderate (approximately 15 ms⁻¹) wind speed breaking wave gas transfer processes account for a fourfold increase in the flux over the modeled interfacial processes.

Rudnick, D.L., R.E. Davis, C.C. Eriksen, D. Fratantoni, M.J. Perry, 2004. Undersea gliders for ocean research. *J. Marine Tech. Soc.*, **38**(2), 73-84.

http://www-pord.ucsd.edu/~rdavis/publications/MTS_Glider.pdf

INTRODUCTION

Underwater gliders are autonomous vehicles that profile vertically by controlling buoyancy and move horizontally on wings. Gliders are reviewed, from their conception by Henry Stommel as an extension of autonomous profiling floats, through their development in three models, and including their first deployments singly and in numbers. The basics of glider function are discussed as implemented by University of Washington in Seaglider, Scripps Institution of Oceanography in Spray, and Webb Research in Slocum. Gliders sample in the archetypical modes of sections and of “virtual moorings.” Preliminary results are presented from a recent demonstration project that used a network of gliders off Monterey. A wide range of sensors has already been deployed on gliders, with many under current development, and an even wider range of future possibilities. Glider networks appear to be one of the best approaches to achieving subsurface spatial resolution necessary for ocean research.

Smith, S. R., 2004: Focusing on improving automated meteorological observations from ships. *EOS, Trans Amer. Geophys. Union*, **85**, 319.

INTRODUCTION

The shipboard automated meteorological and oceanographic system (SAMOS) initiative seeks to improve the accuracy, calibration, availability, and archiving of quality assured marine meteorological measurements collected using SAMOS on research vessels (R/Vs) and select volunteer observing ships (VOS). R/Vs are envisioned to be one component of a sustained ocean observing system that will be implemented over the next decade by U.S. and international partners (NOAA 2003). One goal of the ocean observing system is to provide better estimates of the heat, moisture, and momentum fluxes across the air-sea interface. The planners of the World Ocean Circulation Experiment (WOCE) recognized a need for an improved understanding of air-sea fluxes (Thompson et al. 2001) and a continued need was stated by the World Climate Research Program/Scientific Committee on Oceanic Research (WCRP/SCOR) Working Group on Air-Sea Fluxes (WGASF 2000). High quality, high accuracy fields of air-sea fluxes are necessary to achieve the scientific objectives of the Climate Variability and Predictability program (CLIVAR; WCRP 1995) and to support the activities of the Global Ocean Data Assimilation Experiment (GODAE). Over the ocean surface, these fields can be derived using in-situ and remotely sensed observations in combination with flux models and data assimilation systems. Regardless of the method used to derive the flux fields, there will be a need to benchmark the fields to some independent standard. Understanding the biases and uncertainties in global flux fields is necessary because poor quality fields can result in unrealistic ocean currents and heat transports when they are used to force an ocean model. The planners of a sustained ocean observing system look to future SAMOS installations as an excellent source of validation data for the flux fields (e.g., NOAA 2003, Smith et al. 2003).

Sabine, C.L., R.A. Feely, N. Gruber, R.M. Key, K. Lee, J.L. Bullister, R. Wanninkhof, C.S. Wong, D.W.R. Wallace, B. Tilbrook, F.J. Millero, T.-H. Peng, A. Kozyr, T. Ono, and A.F. Rios, 2004b: The oceanic sink for anthropogenic CO₂. *Science*, **305**, 367–371.
http://www.ocean.washington.edu/courses/oc588/Sabine2004_CO2sink.pdf

ABSTRACT

Using inorganic carbon measurements from an international survey effort in the 1990s and a tracer-based separation technique, we estimate a global oceanic anthropogenic carbon dioxide (CO₂) sink for the period from 1800 to 1994 of 118 ± 19 petagrams of carbon. The oceanic sink accounts for 48% of the total fossil-fuel and cement-manufacturing emissions, implying that the terrestrial biosphere was a net source of CO₂ to the atmosphere of about 39 ± 28 petagrams of carbon for this period. The current fraction of total anthropogenic CO₂ emissions stored in the ocean appears to be about one-third of the long-term potential.

Lumpkin, R. and S. L. Garzoli, 2005: Near-surface Circulation in the Tropical Atlantic Ocean. *Deep-Sea Res. I* **52**(3),495-518, 10.1016/j.dsr.2004.09.001.
http://www.aoml.noaa.gov/phod/dac/drifter_climatology.html

DESCRIPTION

Satellite-tracked SVP drifting buoys (Sybrandy and Niiler 1991; Niiler 2001) provide observations of near-surface circulation at unprecedented resolution. Since 1997, a joint SIO/AOML program has focused upon seeding the tropical Atlantic Ocean with these drifters as part of the Global Ocean Observing System. This effort has enormously increased the dataset of drifter observations in this region (Lumpkin and Garzoli 2005). A drifter is composed of a surface float, which includes a transmitter to relay data, a thermometer which reads temperature a few centimeters below the air/sea interface, and a submergence sensor used to detect when/if the drogue is lost. The surface float is tethered to a subsurface float which minimizes rectification of surface wave motion (Niiler et al. 1987; Niiler et al. 1995). This in turn is tethered to a holey sock drogue, centered at 15 m depth. The drifter follows the flow integrated over the drogue depth, although some slip with respect to this motion is associated with direct wind forcing (Niiler and Paduan 1995). This slip is greatly enhanced in drifters which have lost their drogues (Pazan and Niiler 2000). Drifter velocities are derived from finite differencing their raw position fixes. These velocities, and the concurrent SST measurements, are archived at AOML's Drifting Buoy Data Assembly Center where the data are quality controlled and interpolated to 1/4-day intervals (Hansen and Herman 1989; Hansen and Poulain 1996).

Miller, L., and B. C. Douglas, 2004: Mass and volume contributions to 20th century global sea level rise. *Nature*, **428**, 406-408.
<http://www.pol.ac.uk/ntslf/royalsociety2004.abstracts/douglas.doc>

Both the rate and causes of 20th century global sea level rise (GSLR) are the subjects of intense controversy. Estimates from tide gauges range from about 1.0-2.0 mm/yr. In contrast, values based on the two processes that must be principally responsible for GSLR --mass increase (from mountain glaciers and the great high latitude ice masses) and volume increase (expansion due to ocean warming) -- fall below this range. Either the gauge estimates are too high, or one (or both) of the component estimates is too low. Gauge estimates have long been controversial because of vertical land movements, especially due to glacial isostatic adjustment (GIA), and more recently the possibility that coastal tide gauges are subject to exaggerated rates of sea level rise because of localized ocean warming. Presented here are two approaches to a resolution of these problems. The first is heuristic, based on the limiting values of observed trends of 20th century relative sea level rise as a function of the distance from the center of the

ice loads at the last glacial maximum. This observational approach, which does not depend on a geophysical model of GIA, supports values of GSLR above 1.5 mm per year. The second approach involves an analysis of gauge and hydrographic (*in-situ* temperature and salinity) observations in the Pacific and Atlantic Oceans. It shows that gauge-measured sea level rates are in fact free from anomalous thermal effects. Thus sea level trends from tide gauges, which reflect both mass and volume change, are 2-3 times higher than hydrographic based rates which only reveal volume change. These results support those studies that put the 20th century rate in the higher end of the 1.0-2.0 mm/yr range, and provides the first clear evidence that mass increase plays a larger role than ocean warming in 20th century GSLR.

McPhaden, M. J., and D. Zhang, 2004: Pacific Ocean circulation rebounds. *Geophys. Res. Lett.*, **31**, L18301, doi:10.1029/2004GL020727.

<http://www.agu.org/pubs/crossref/2004/2004GL020727.shtml>

ABSTRACT

Recent observations indicate that the shallow meridional overturning circulation in the tropical Pacific Ocean has rebounded since 1998, following 25 years of significantly weaker flow. McPhaden and Zhang compared the 5-6 year average conditions before and after 1998 in the Pacific and report a recent increase in equatorward flow in the upper ocean linked to a change in the Pacific Decadal Oscillation. The circulation increase is also related to a strengthening of the trade winds, changes in the equatorial sea level, and the development of anomalously cool equatorial Pacific sea surface temperatures. The authors suggest that the changes may have affected the global climate and Pacific marine ecosystems. A pattern of stronger circulation was the norm prior to 1976-77, when weaker overturning flow began to dominate the Pacific. The researchers suggest that the abruptness of the circulation recovery in 1998 obscures presumed manmade warming trends indicated in the instrumental records from the tropical Pacific.

Reynolds, R. W, C. L. Gentemann, and F. Wentz, 2004: Impact of TRMM SSTs on a climate-scale SST analysis. *J. Climate*, **17**, 2938-2952.

[http://ams.allenpress.com/amsonline/?request=get-abstract&doi=10.1175%2F1520-0442\(2004\)017%3C2938:IOTSOA%3E2.0.CO%3B2](http://ams.allenpress.com/amsonline/?request=get-abstract&doi=10.1175%2F1520-0442(2004)017%3C2938:IOTSOA%3E2.0.CO%3B2)

ABSTRACT

Prior efforts have produced a sea surface temperature (SST) optimum interpolation (OI) analysis that is widely used, especially for climate purposes. The analysis uses in situ (ship and buoy) and infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR). Beginning in December 1997, "microwave" SSTs became available from the Tropical Rainfall Measuring Mission (TRMM) satellite Microwave Imager (TMI). Microwave SSTs have a significant coverage advantage over "IR" SSTs because microwave SSTs can be retrieved in cloud-covered regions while IR SSTs cannot. However, microwave SSTs are at a much lower spatial resolution than the IR SSTs.

In this study, the impact of SSTs derived from TMI was tested from the perspective of the OI analysis. Six different versions of the OI were produced weekly from 10 December 1997 to 1 January 2003 using different combinations of AVHRR and TMI data and including versions with and without a bias correction of the satellite data. To make the results more objective, 20% of the buoys were randomly selected and the SSTs from these buoys were withheld from the OI for independent verification. The results of the intercomparisons show that both AVHRR and TMI data have biases that must be corrected for climate studies. These biases change with time as physical properties of the atmosphere change and as satellite instruments and the orbits of the satellites, themselves, change. It is critical to monitor differences between satellite and other products to quickly diagnose any of these changes. For the OI analyses *with* bias correction, it is difficult using the withheld buoys to clearly demonstrate that there is a significant

advantage in adding TMI data. The advantage of TMI data is clearly shown in the OI analyses *without* bias correction. Because IR and microwave satellite algorithms are affected by different sources of error, biases may tend to cancel when both TMI and AVHRR data are used in the OI. Bias corrections cannot be made in regions where there are no in situ data. In these regions, the results of the analyses without bias corrections apply. Because there are areas of the ocean with limited in situ data and restricted AVHRR coverage due to cloud cover, the use of both TMI and AVHRR should improve the accuracy of the analysis in these regions. In addition, the use of more than one satellite product is helpful in diagnosing problems in these products.

Rigor, I. G., and J. M. Wallace, 2004: Variations in the Age of Sea Ice and Summer Sea Ice Extent, *Geophys. Res. Lett.*, **v31**, doi:10.1029/2004GL019492.
<http://iabp.apl.washington.edu/IceAge&Extent/>

INTRODUCTION

Three of the past six summers have exhibited record low sea-ice extent on the Arctic Ocean. These minima may have been dynamically induced by changes in the surface winds. Based on results of a simple model that keeps track of the age of ice as it moves about on the Arctic Ocean, we show that the areal coverage of thick multi-year ice decreased precipitously during 1989–1990 when the Arctic Oscillation was in an extreme “high index” state, and has remained low since that time. Under these conditions, younger, thinner ice anomalies recirculate back to the Alaskan coast more quickly, decreasing the time that new ice has to ridge and thicken before returning for another melt season. During the 2002 and 2003 summers this anomalously younger, thinner ice was advected into Alaskan coastal waters where extensive melting was observed, even though temperatures were locally colder than normal. The age of sea-ice explains more than half of the variance in summer sea-ice extent.

Rudnick, D. L., R. E. Davis, C. C. Eriksen, D. Fratantoni, and M. J. Perry, 2004: Undersea gliders for ocean research. *J. Marine Tech. Soc.*, **38 (2)**, 73-84.
http://www-pord.ucsd.edu/~rdavis/publications/MTS_Glider.pdf

INTRODUCTION

Underwater gliders are autonomous vehicles that profile vertically by controlling buoyancy and move horizontally on wings. Gliders are reviewed, from their conception by Henry Stommel as an extension of autonomous profiling floats, through their development in three models, and including their first deployments singly and in numbers. The basics of glider function are discussed as implemented by University of Washington in Seaglider, Scripps Institution of Oceanography in Spray, and Webb Research in Slocum. Gliders sample in the archetypical modes of sections and of “virtual moorings.” Preliminary results are presented from a recent demonstration project that used a network of gliders off Monterey. A wide range of sensors has already been deployed on gliders, with many under current development, and an even wider range of future possibilities. Glider networks appear to be one of the best approaches to achieving subsurface spatial resolution necessary for ocean research. to the problem at hand; global distribution is appropriate for climate problems, while a study of, say, biophysical interactions in mesoscale eddies would require more focused deployments. A second advantage of small platforms is that they are readily portable to sample phenomena that may be intermittent and localized, such as mixing and upwelling events, and phytoplankton blooms. The scalability and portability of a fleet of autonomous platforms make them essential infrastructure for ocean research.

Takahashi, T., 2004: The fate of industrial carbon dioxide. *Science*, **305**, 352-354.
http://www.ocean.washington.edu/courses/oc588/Takahashi2004_FateCO2.pdf

INTRODUCTION

The atmospheric CO₂ concentration has increased from about 280 parts per million (ppm) in 1800—the beginning of the industrial age—to 380 ppm today (1). During this time, the observed annual rate of increase has been about 50% of that expected from the estimated industrial CO₂ emission rate into the atmosphere. This means that an amount of CO₂ equivalent to about one-half of the industrial CO₂ emitted each year has been missing, and thus Earth's atmosphere is receiving only one half the full impact of the anthropogenic CO₂ emissions. What process has been taking up the “missing carbon”? An answer to this question is fundamental not only for our understanding of the natural carbon cycle, but also for formulating a sound global CO₂ emission strategy. As reported on page 367 of this issue, Sabine *et al.* (2) used an extensive data set obtained for CO₂ concentration and other chemical properties during recent global oceanographic programs, together with a computational method developed by Gruber *et al.* (3), and provided a solid estimate for the total amount of CO₂ taken up by the global oceans from 1800 to 1994. Their results show that the oceans store a major proportion of the anthropogenic CO₂ and provide a better understanding of the carbon cycle.

Willey, D. A., R. A. Fine, R. E. Sonnerup, J. L. Bullister, W. M. Smethie, Jr., and M. J. Warner 2004: Global oceanic chlorofluorocarbon inventory. *Geophys. Res. Lett.*, **31**, L01303, doi:10.1029/2003GL018816.
<http://www.agu.org/journals/gl/gl0401/2003GL018816/>

ABSTRACT

Chlorofluorocarbons (CFCs) dissolve in the oceans, but the total quantity and spatial distribution in the oceans was not previously known. The first estimate of the global oceanic CFC-11 uptake using field measurements is calculated from WOCE (World Ocean Circulation Experiment) CFC-11 concentrations. Here we find the total oceanic uptake of $5.5 (\pm 1.2) \times 10^8$ moles was about 1% of total emissions through 1994. Eighty-two percent of the CFC-11 inventory is in the upper 1000 meters. The CFC inventory distribution implies that the dominant physical air-sea exchange of gases on decadal time scales occurs due to a combination of high gas solubility in cold high latitude waters and effectiveness of the wind-driven circulation. The global inventory provides a benchmark for models simulating climate change.

4.2 Bibliography of Science Articles and Reports Published by OCO-funded Scientists During FY 2004

A bibliography of all science publications published during FY 2004 is found below. Articles are separated into published articles and articles in press, books and book chapters, submitted articles, articles in preparation, reports and memos, proceedings, abstracts, encyclopedia entries, newsletters, and brochures and pamphlets.

Legend for projects affiliated with publications

A key is provided to show the affiliation between each published article and the science projects shown below (PI = Principal Investigator; co-PI = co-Principal Investigator; PM = Project Manager; PL = Project Leader; S = Scientists).

- A. Atlantic High Density XBT Lines (PMs: Baringer, Goni, Garzoli)
- B. Western Boundary Time Series in the Atlantic Ocean (PMs / S: Baringer, Garzoli / Johns, Meinen)
- C. The Tropical Atmosphere Ocean (TAO) Array (PM: Bernard)
- D. ENSO Observing System (PMs: Cook, Molinari)
- E. Surface Fluxes and Analysis (PL: Cayan)
- F. Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific (PLs: Cornuelle, Stammer, Miller)
- G. Underwater Gliders for Monitoring Ocean Climate (PL: Davis)
- H. Drifter Observations (PL: Niiler)
- I. High Resolution XBT/XCTD (HRX) Transects (PL: Roemmich)
- J. Development of an Underway CTD (PL: Rudnick)
- K. Lagrangian Salinity Profiling: Evaluation of Sensor Performance (PL: Schmitt)
- L. Observations of Air-Sea Fluxes and the Surface of the Ocean (PIs: Weller, Bahr, Hosom)
- M. Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO) (PI / co-PIs: Cronin / Meinig, Sabine)
- N. High Resolution Climate Data from Research and Volunteer Observing Ships (PM: Fairall)
- O. Global Repeat Hydrographic/CO₂/Tracer Surveys in Support of CLIVAR and Global Carbon Cycle Objectives: Carbon Inventories and Fluxes (PMs / co-PIs: Feely, Wanninkhof / Sabine, Johnson, Baringer, Bullister, Mordy, Zhang)
- P. Surface Drifter Program (PMs: Garzoli, Molinari)
- Q. National Water Level Program Support Towards Building a Sustained Ocean Observing System for Climate (PMs: Gill, Zervas)
- R. An End-to-End Data Management System for Ocean pCO₂ Measurements (PI / co-PIs: Hankin / Feely, Kozyr, Peng)
- S. Observing System Research Studies (PI: Harrison)
- T. Progress Reports for the Observing System Monitoring Center (OSMC) (PIs: Kern, Hankin)
- U. An Indian Ocean Moored Buoy Array for Climate (PI: McPhaden)
- V. Pilot Research Moored Array in the Tropical Atlantic (PIRATA) (PI: McPhaden)
- W. The University of Hawaii Sea Level Center (PI: Merrifield)
- X. Satellite Altimetry (PM: Miller)
- Y. The Global Drifter Program (PI: Niiler)
- Z. Climate Variability in Ocean Surface Turbulent Fluxes (PI / co-PIs: O'Brien / Smith, Bourassa)
- AA. U.S. Research Vessel Surface Meteorology Data Assembly Center (PI / co-PIs: O'Brien / Smith, Bourassa)
- BB. *In situ* and Satellite Sea Surface Temperature (SST) Analyses (PM: Reynolds)

- CC. Monitoring Ice Thickness in the Western Arctic Ocean (PM: Richter-Menge)
- DD. Monitoring Eurasian Basin of the Arctic Ocean (PM: Rigor)
- EE. High-Resolution Ocean and Atmosphere pCO₂ Time-Series Measurements (PI / co-PI: Sabine / Chavez)
- FF. Document Ocean Carbon Sources and Sinks: Initial Steps Towards a Global Surface Water pCO₂ Observing System Underway CO₂ Measurements on the NOAA ships Ka'imimoana and Ronald H. Brown and RVIB Palmer and Explorer of the Seas (PIs / co-PIs: Wanninkhof, Feely / Bates, Millero, Takahashi, Cook)
- GG. Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS) (PMs: Weller, Plueddemann)
- HH. Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic (Atlantic VOS) (PIs: Weller, Hosom)

Published Articles and Articles in Press

- Auad, G., J. P. Kennett, and A. J. Miller, 2003: The North Pacific Intermediate Water response to a modern climate shift. *J. Geophys. Res.*, **108**, article no.3349. ^(F)
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